CHAPTER 6

CRESTĠATES

6-l. General.

a. The value of an uncontrolled fixed crest spillway in providing an extremely reliable operation and a very low cost maintenance facility is undeniable. Topographical, geological, economical, and political considerations at many damsites may restrict the use of an uncontrolled fixed crest spillway. The solution to these problems is usually the inclusion of crest gates; however, the uncontrolled fixed crest spillway should be used regardless of these considerations when the time of concentration of the basin runoff into the reservoir is less than 12 hours. When the time of concentration is between 12 and 24 hours, an uncontrolled fixed crest spillway should be given preference over a gated spillway. Basically, the inclusion of crest gates allows the spillway crest to be placed significantly below the maximum operating reservoir level, in turn permitting the entire reservoir to be used for normal operating purposes; and results in a much narrower spillway facility, avoiding the problems associated with high unit discharge/high-velocity flow and increased operation and maintenance costs. A gated spillway must include, as a minimum, two or preferably three spillway gates in order to satisfy safety concerns. Two common types of crest gates used extensively by the CE are the tainter (radial) gate and the vertical lift gate. These and other types of crest gates have been used throughout the world. This manual discusses only the tainter and vertical lift gates. A good discussion of all types of gates can be found in item 27.

b. The hydraulic design of crest gates involves the determination of the hydrostatic and hydrodynamic forces acting on the gate and crest in the immediate vicinity of the gate; the design and evaluation of gate seals, seats, and slots with respect to flow-induced vibrations and cavitation-related problems; the determination of the rate of flow from partially open gates; and the evaluation of gate seat locations, the trunnion elevation, and other hydraulics-related structural features.

6-2. Tainter Gates. Recent controlled crest spillway designs tend to favor use of the tainter gate almost exclusively over any other type of crest gate. This is due to the relatively inexpensive first cost and the ease and low cost of operation and maintenance. The conventional tainter gate consists of a skin plate and a framework of horizontal and vertical members all of which are formed to a segment of a cylinder. This cylindrical segment is held in place by radial struts that converge downstream to a central location called the trunnion. The cylindrical skin plate structure is concentric to the trunnion which causes the resultant of the hydrostatic force to pass through the trunnion; thus, there is no moment resulting from this force to be overcome by the gate hoist. The gate lip is essentially sharp-edged, which results in minimizing downpull forces as well as vibration-inducing forces. The main load that the hoist must accommodate is a portion of the gate weight, side seal friction, and trunnion friction. The tainter gate does not require slots in the pier. This type of gate is noted for good discharge characteristics.

a. Gate Size and Trunnion Location. The tainter gate height is dependent upon the required damming height between the gate seat elevation and the maximum operating elevation. The gate width is related to the spillway monolith width because spillway piers are normally located in the center of the monolith with the gate spanning the space between the piers and the monolith joint. The gate trunnion is located above the water surface of the maximum uncontrolled discharge (see Chapters 2 and 3 for water surface profile determination). Usually the water surface location and gate geometry are such that the trunnion can be located at the optimum structural location of one-third the vertical distance above the lip of the gate. The horizontal location of the trunnion is dependent upon the gate seat location and the gate radius. Table 6-l shows the major dimensions of some of the large tainter gates used on the Columbia River Basin Projects. There appears to be no reason that gates significantly larger than those listed in Table 6-l could not be used. The only constraints on gate size are economics and safety. Safety considerations require that at a minimum two spillway gates should be provided. Three gates are preferred to satisfy safety concerns.

TABLE 6-l

Major Tainter Gate Dimensions, Feet

Project	Height	Width	Gate Radius	Horizontal Distance Seat To Crest	Vertical Distance Trunnion To Seat
Lower Monumental	60.6	50.0	60.0	11.2	18.6
John Day	60.0	50.0	60.0	10.2	20.0
Libby	56.0	48.0	55.0	15.6	18.1
Chief Joseph	58.2	36.0	55.0	10.7	20.2
Dworshak	56.7	50.0	55.0	7.0	18.0

b. Gate Seat Location. The location of the gate seat affects the height of the gate, the local crest pressures, and the discharge coefficients at partial gate openings. The coefficient effect is relatively unimportant from a design standpoint, as the gate opening can be adjusted to obtain the desired discharge. The gate seat should not be located upstream of the crest axis, as the jet issuing under the gate would tend to spring away from the crest boundary, resulting in negative pressures and possible cavitation damage on the crest. The gate seat can be located either on or downstream from the crest apex. The location of the gate seat is usually dictated by structural requirements such as the spillway bridge, hoist equipment location, etc. The gate seat location influences the trunnion location and the height that the gate must be raised to clear the water surface at the maximum uncontrolled discharge. Gate and trunnion clearance above the maximum uncontrolled discharge profile should include considerations for floating debris and ice and inaccuracies in the flow profile. Impact to the gate and trunnion by debris, ice, or high-velocity flow should be avoided.

c. Discharge Coefficient. The development of the rating curve for a partly open unsubmerged tainter gate, mounted on a spillway crest, is based on the following high head orifice equation:

$$Q = CW_bG_o\ (2gH)^{1/2} \tag{6-1}$$

where

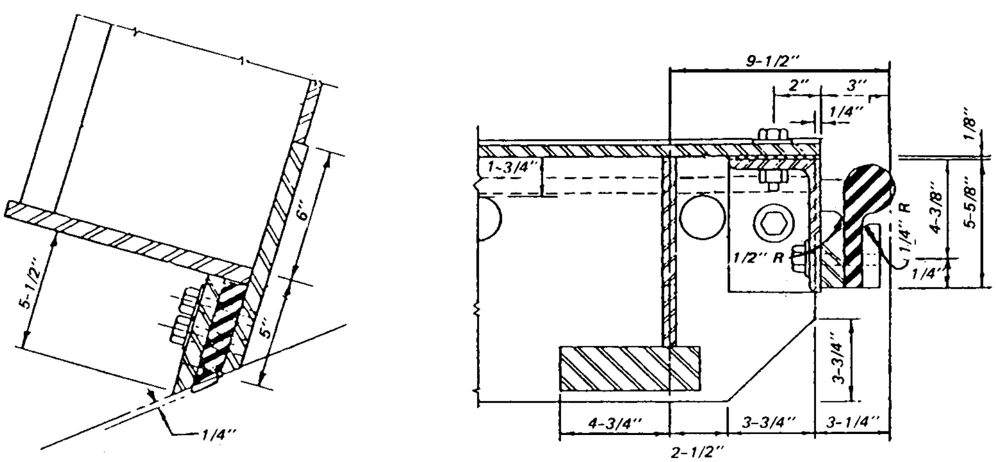
W_b = gate width, feet
G_0 = gate opening, minimum distance from gate lip to crest boundary, feet
H = distance from reservoir surface to center of G_o, feet

Plate 6-l shows suggested design discharge coefficient curves for various gate seat locations. The data points were computed from model and prototype data for several crest shapes and tainter gate designs with nonsubmerged flow. Data shown are based principally on tests with three or more bays in operation. Discharge coefficients for a single bay would tend to be lower because of side contractions. The discharge coefficient C shown in Plate 6-l is plotted as a function of the angle β formed by the tangent to the gate lip and the tangent to the crest curve location intersected by the minimum distance line from the gate lip to the crest (see sketch in Plate 6-l). The computation of discharge under a partially open spillway crest tainter gate is complicated by the geometry involved in determining the gate opening, G_o, and the β angle the gate lip makes with the crest. HDC 311-1 through 311-5 describe a method for the numerical solution of G_o and β. The CORPS program H3106 will perform the numerical solution for the gate opening and the discharge.

d. Crest Pressure. Flow characteristics at a control section gate are conducive to low pressures. Depending upon the situation, the pressure may be low enough to result in cavitation. Upstream from a gated spillway crest the flow velocity and resulting turbulence along the crest boundary are of a very low magnitude. At the control section a very rapid acceleration of the flow occurs without extensive turbulent boundary layer development. Thus, the velocity immediately adjacent to the crest boundary is essentially the potential velocity. As the turbulent boundary develops, the velocity immediately against the crest boundary becomes less than the average velocity. Because of the lack of a turbulent boundary layer near the control section, cavitation is much more likely to be tripped by surface irregularities here than further downstream. The pressure regime on the spillway crest boundary resulting from flow under a partially open tainter gate is a function of gate opening, gate radius, trunnion location, and hydraulic head on the gate. Lemos' results (item 25) indicate that the effects of radius and trunnion location are small and can be neglected. Dimensionless crest pressure profiles for small, medium, and large gate openings for the design head and for 1.33 times the design head are given in Plates 6-2 and 6-3, respectively. These data indicate that with the gate seat on the crest axis, a minimum pressure of about $-0.2H_d$ can be expected on the spillway crest with a gate partially open and with the reservoir pool at $1.33H_d$. The data also show that the pressures are somewhat higher with the gate seat located downstream from the crest axis.

As an example, for a spillway with gates operating under a 53-foot head on a crest designed for a 40-foot head, a minimum pressure on the crest surface of -8 feet can be expected and a potential velocity of about 58 ft/sec. A pressure-velocity combination of the magnitude in the example has the same potential for cavitation at surface irregularities as a pressure of zero and velocity of 73 ft/sec. Where cavitation damage has occurred at control sections in the field, with pressures at about zero, velocities have been in excess of 100 ft/sec. The magnitude of surface irregularities (tolerances) that can be allowed in the vicinity of the tainter gate should be developed using the potential velocity and the procedures discussed in Section VI of Chapter 2. Pressure fluctuations on the spillway crest boundary have been investigated at both Chief Joseph Dam and Table Rock Dam (items 64 and 68). These investigations have shown that pressures as low as -3.2 feet of water occurred at Chief Joseph Dam at a large gate opening. The pressure fluctuations recorded were random and are considered to be caused by the development of the turbulent boundary layer.

e. Gate Seals. Tainter gates included on spillways for multipurpose reservoir projects normally include rubber seals on both the sides and bottom of the gate. The design and construction of the sealing system must be precise for the seal to function as planned. The design of the bottom seal is critical because an incorrectly designed bottom seal can become the cause of flow-induced vibrations that could damage the gate. Figure 6-l shows a typical detail for both the side and the bottom seal. EM 1110-2-1605 is referenced as a source of additional information on tainter gate seals.



Bottom seal   Side seal

Figure 6-l. Typical details for tainter gate seals

In the northern latitudes where freezing temperatures can occur, seal heaters are usually provided. The most common type of heater is a system that circulates heated fluid through tubes attached to the concrete side of the seal plates. Studies should be made to determine if heating the seals of every gate is required. Studies showed that at Chief Joseph Dam side seal heaters were required for only 9 of the 19 gates.

6-3. Vertical Lift Gates. The vertical lift gate is rectangular in shape and consists of a structural frame to which a flat skin plate is attached, normally on the upstream face. The hydrostatic load on-the gate is transferred to the concrete structure through surfaces located in slots formed into the sides of the piers. The gate moves vertically within these slots in its own plane on a type of sliding bearing which characterizes the gate as a slide gate, wheel gate, tractor gate, etc. The hoisting system frequently consists of a track-mounted gantry crane which can be moved from gate to gate for opening and closing operations. This procedure leads to an expensive operation due to its labor intensiveness. For this reason, some projects have been designed or modified to include individual hoists for each gate. The principal hydraulic design aspects of the vertical lift gate are the shape of the bottom lip, the shape of the gate slots, and the determination of the hydraulic capacity.

a. Gate Bottom Shape. High-velocity flow under the vertical lift gate has a substantial influence on the hydraulic downpull (increased hoist load) or upthrust. The hydrodynamics of the flow under a gate may cause vertical oscillations (vibrations). Both of these conditions are dependent upon shape of the geometry of the gate bottom. Discussion, data, and references that would be useful for hydrodynamic load analysis on vertical lift gates can be found in HDC 320-2 to 320-2/3. Vibrations of the vertical lift spillway gates at Bonneville Dam were eliminated by a change in the gate bottom geometry (item 15).

b. Gate Slots. Flow past a discontinuity such as a gate slot will result in lowering the localized pressure immediately downstream from the discontinuity. Model and prototype data have shown that low pressures exist in and downstream from gate slots formed into the sides of spillway piers, and that with specific slot geometry and flow conditions, these pressures can be low enough to result in cavitation-induced damage. This is especially significant with projects that operate at heads greater than 40 feet with small gate openings. Proper geometric proportions of the slot will assist in maintaining higher boundary pressures in the vicinity of the slot. Details of various slot geometry and resulting pressure regimes are described in HDC 212-l through 212-l/2. Spillways for hydroelectric projects usually provide for use of spillway bay bulkheads upstream from the spillway service gate. Normally these bulkheads are vertical lift type which require slots in the pier to hold the bulkhead. These slots are usually located at or upstream from the crest and sometimes extend into the pier nose geometry. Model studies for John Day Dam (item 38) included detailed studies of various bulkhead slot locations and shape. These studies led to the present use of the 90-degree upstream edge on the slot. Model studies for Chief Joseph Dam (item 57) included the John Day Dam type slot and investigated the shape of the downstream return to the pier face. The results of these studies can be applied to vertical lift gate slot design equally as well.

c. Discharge Coefficients. The discharge under a vertical lift gate can be derived using the basic orifice equation described in equation 6-l.

The coefficient of discharge used must be based on vertical lift gates on spillway crests. WES (item 70) has developed a concept of relating vertical lift gate controlled discharge to free discharge. This procedure requires the determination of the head-discharge relationship for free flow. See Chapters 2 and 3 and the determination of gate opening to head on the crest ratio as described in Plate 6-4. See HDC 312 for additional information on vertical lift gate discharge coefficients.

6-4. Ice and Wave Forces on Gates. Horizontal forces acting on gates can be caused by both wind waves and ice or a combination of both. The periodic force of-waves on the gate should be considered when there is sufficient reservoir fetch to generate substantial waves. There is adequate theory presented in various texts including the CE "Shore Protection Manual" (item 74) to develop these wave forces. Forces against a gate can be caused by ice in various forms. Expanding sheet ice has been the subject of considerable study. A large force can also be induced by either current- or wind-driven floe ice. The possibility also exists for local impact forces to occur from blocks of ice impelled by breaking waves. Design of spillway gates in the northern latitudes and/or at high elevations should include studies to determine ice loads. EM 1110-2-1612 should be consulted for additional information on ice forces.